Pointers and Arrays

FRIDAY, MAY 2

Today we'll learn about pointers and arrays in C++ as we build up the toolkit we will need to implement awesome ADTs like vectors and stacks.

- 📚 Readings: Text 11.1, 11.2, 11.3
- 📝 Lecture quiz on Canvas
- 🎬 Lecture video on Canvas

Lecture Video

Click to sign in and play video

Contents

1. Preliminary Note: Don't Panic!

2. Preliminaries: Returning Vectors from Functions

3. Memory Addresses

4. Pointers

5. Style Note: Pointer Declarations

6. The Ampersand Operator Means Different Things in Different Contexts!

7. Dreferencing Pointers

8. The Asterisk Operator Means Different Things in Different Contexts!

9. Other Odds and Ends

10. Treasure Hunt

11. Arrays

12. The Relationship Between Pointers and Arrays: Naked Array Variable Names

13. Arrays Are Dangerous! (and Segmentation Faults)

14. **Supplementary** Pointers to Nowhere: `nullptr`

15. **Supplementary** An Obscure Dereferencing Trick

16. What's next?

17. Exam Prep

Preliminary Note: Don't Panic!

A word before we dive into today's lecture notes:

Pointers can feel quite intimidating when you first see them. Memory addresses look wonky and wild (they're just numbers, but they're represented using base 16, or "hexadecimal"), and there are a lot of obnoxious syntax details to parse through, like the fact that the `&` and `*` operators mean different things in different contexts. If you're feeling a bit lost in today's lecture, don't panic! That's totally normal. To get comfortable with pointers, you'll need to spend a lot of time toying with code, moving asterisks and ampersands around in your code, printing out memory addresses, and drawing lots of diagrams to help make sense of what's going on in memory.

The other intimidating thing is that the utility of pointers won't be immediately clear from today's lecture, but I promise we will see a use for them soon (in our next class). In the meantime, take some time to focus on mastering the use of pointers in small, somewhat accessible programs that don't do anything particularly useful.

Preliminaries: Returning Vectors from Functions

I started class today by talking about the following function:

```
Vector<int> createRandoVector(int n)
{
   Vector<int> v;

   for (int i = 0; i < n; i++)
   {
      v.add(randomInteger(1, 100));
   }

   return v;
}
```

Recall from our discussion of C++ classes and object-oriented programming on Wednesday (when we talked about destructor functions) that local variables die when we leave a function. Since the vector in our `createRandoVector()` function dies when we hit the `return` statement in the code above, it is not actually returning the vector that function created. Rather, our program generates a *copy* of that vector back back in the function that called this one. This is a problem because creating a new copy of that vector could potentially be a slow operation. This is especially problematic if that vector contains a lot of elements that need to be copied.

So, our goal over the next few classes is to talk about how we can create variables that live beyond the lifespan of a function -- a sort of programming necromancy, if you will. If we can do that, then we'll be able to return a vector from a function without having to go through the slow operation of creating a new copy of that vector! Before we can get there, however, we need to spend a day discussing one of the primary tools of this so-called programming necromancy: **pointers**.

Memory Addresses

Before we defined what a pointer is, we saw today that every variable we create in C++ has an address where it resides in memory. To access the address associated with a variable, we place an ampersand in front of the variable name, like so:

main.cpp

```
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int x = 55;

   cout << "x : " << x << endl;
   cout << "&x : " << &x << endl;

   return 0;
}
```

memory diagram

```
main():

  x   0x7fe7f49e0c34
  +----------------+
  |       55       |
  +----------------+
```

output

```
x : 55
&x : 0x7fe7f49e0c34
```

Pointers

What if we want to store that memory address in a variable? It's quite a wonky-looking thing. It's certainly not an integer, and it's actually not a string, either. If we want to store that address in a variable, we need a new datatype. That's where pointers come in.

(*Key take-away!*) A **pointer** is simply a variable that holds a memory address. You can think of it as an address book that's only capable of holding a single address, or a cell phone that's only capable of storing a single phone number.

To create a pointer, we need to know what *kind* of address it will be holding. Is it the address of an `int` ? A `string` ? A `Quokka` object?

The syntax for creating a pointer is as follows:

```
DATA_TYPE_POINTED_TO  * VARIABLE_NAME ;
```

For example, to create a variable named `p` that can hold the address of an integer, the syntax is as follows:

```
int *p;
```

Here's that idea in action:

main.cpp

```
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int x = 55;
   int *p = &x;

   cout << "x : " << x << endl;
   cout << "&x : " << &x << endl;

   cout << endl;

   cout << "p : " << p << endl;
   cout << "&p : " << &p << endl;

   return 0;
}
```

memory diagram

```
main():

  x   0x7fbc09bdfc2c
  +----------------+
  |       55       |
  +----------------+

  p                   0x7fbc09bdfc30
  +--------------------------------+
  |          0x7fbc09bdfc2c        |
  +--------------------------------+
```

output

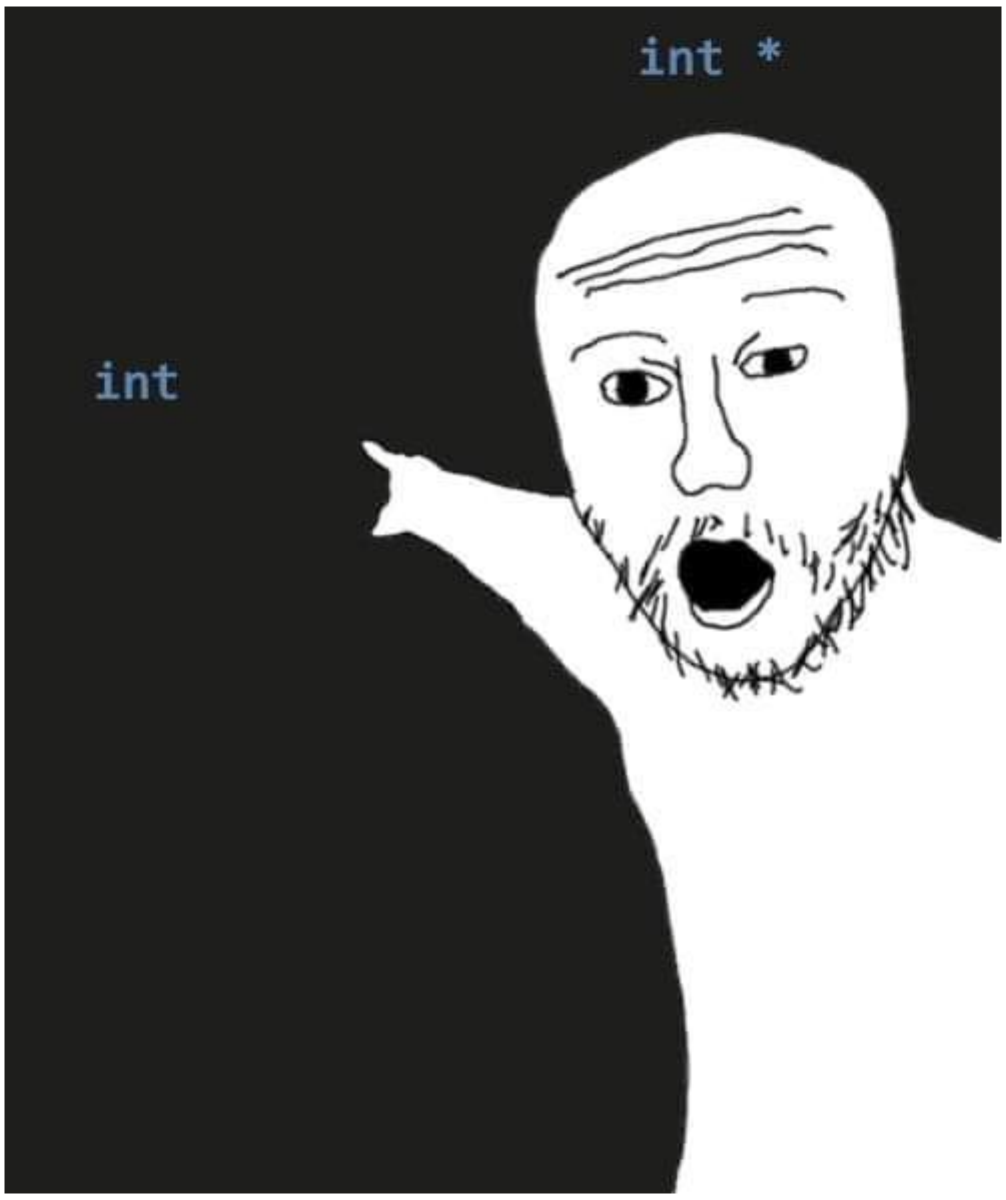
```
x : 55
&x : 0x7fbc09bdfc2c

p : 0x7fbc09bdfc2c
&p : 0x7fbc09bdfc30
```

Notice above that the value inside `p` is the address of `x`, but `p` has its own address, distinct from the address of `x`.

We say that `p` now **points to** `x`. We say also that `p` is now **a pointer** to `x`. One can imagine going up to the variable `p` and saying, "Hey, do you know where `x` is?" and `p` **pointing** over at `x` (which it can do because it knows the address where `x` is hanging out).

In other words, we have this:



Style Note: Pointer Declarations

When creating pointers, some people prefer this:

```
int* p;
```

...over this:

```
int *p;
```

Both compile just fine and mean the same thing, but some people prefer the former approach because variable declarations have always looked like this in C++:

```
DATA_TYPE   VARIABLE_NAME
```

The former approach matches that pattern, since `int*` is our data type. The latter approach seems aberrant, as it introduces a space in the middle of the data type itself rather than between the data type and the variable name.

However, if we do this:

```
int* p, q, r;
```

...we actually only get one pointer: `p`. In this case, `q` and `r` are actually just regular integers -- not pointers! 🤯

So, some people consider the former approach to pointer declaration to be a bit misleading, since it makes it look like the `*` would apply to all the variables declared on a single line, when it in fact only applies to the first variable in a list like that. People who fall into this camp instead prefer the following style to emphasize that there needs to be a `*` for each variable:

```
int *p;
int *q, *r, *s;
```

With that said, both are acceptable, and you are welcome to use whichever one feels more comfortable to you.

The Ampersand Operator Means Different Things in Different Contexts!

(*Super Important!*) One of the more obnoxious things about learning how pointers work in C++ is that C++ uses the ampersand operator to mean a few completely different things in different contexts. As relates to memory manipulation, there are actually **two** uses of the `&` operator:

- When we use `&` in a variable DECLARATION, that creates a REFERENCE.
- When we use `&` on an ALREADY-EXISTING variable, that gives us its ADDRESS.

For example:

```
#include <iostream>
#include "console.h"
#include "vector.h"
using namespace std;

// On the following line, the & is used in a variable declaration (we are creating a
// new variable, v), and so it is being used to create a reference.
void populateVector(Vector<int>& v, int value)
{
   for (int i = 0; i < v.size(); i++)
   {
      v[i] = value;
   }
}

int main()
{
   int x = 55;

   // On the following line, the & is being applied to an already-existing variable, x,
   // and so it is being used to give us the address of that variable. It is not
   // creating a new reference variable.
   cout << "&x : " << &x << endl;

   return 0;
}
```

Dreferencing Pointers

We can actually use a pointer to modify the contents of the variables they point to indirectly. To do that, we apply an asterisk (`*`) to a pointer variable. The asterisk says, "Hey, I know you're a pointer. That means the value you hold is some memory address. Let's go to that memory address!" This is called **dereferencing** our pointer.

Here's an example of that in action:

main.cpp

```
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int x = 55;
   int *p = &x;

   // Here, we dereference p. We go to the address p holds, and that is where
   // we drop off the value 30. Notice that we are not setting p = 30. (We're
   // not dropping the value 30 into the box called p.)
   *p = 30;

   cout << "x : " << x << endl;
   cout << "&x : " << &x << endl;

   cout << endl;

   cout << "p : " << p << endl;
   cout << "&p : " << &p << endl;

   // We can also dereference p to find out what value is in the variable that
   // it's pointing to! The following line does not print the value inside p
   // itself. It goes to the address that p contains and tells us what it finds
   // in the box at that address.
   cout << "*p : " << *p << endl;

   return 0;
}
```

memory diagram

```
main():

  x   0x7fbc09bdfc2c
  +----------------+
  |       30       |
  +----------------+

  p                   0x7fbc09bdfc30
  +--------------------------------+
  |          0x7fbc09bdfc2c        |
  +--------------------------------+
```

output

```
x : 30
&x : 0x7fbc09bdfc2c

p : 0x7fbc09bdfc2c
&p : 0x7fbc09bdfc30
*p : 30
```

The Asterisk Operator Means Different Things in Different Contexts!

Just as the ampersand operator means different things in C++ in different contexts, so too does the asterisk. As relates to memory manipulation, there are actually **two** uses of the `*` operator:

- When we use `*` in a variable DECLARATION, that creates a POINTER.
- When we use `*` on an ALREADY-EXISTING variable, that DEREFERENCES our pointer. (In other words, it GOES to the address that our pointer is pointing to and then proceeds to operate on whatever variable it finds there.)

For example:

```
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int x = 55;

   // On the following line, the * is used in a variable declaration (we are creating a
   // new variable, p), and so it is being used to create a pointer.
   int *p = &x;

   // On the following line, the * is being applied to an already-existing variable, p,
   // and so it is being used to dereference of that variable. It is telling us to go
   // to whatever address p contains (the address of x) and drop the 30 off there (in x).
   *p = 30;

   // This will print 30 now.
   cout << x << endl;

   return 0;
}
```

Other Odds and Ends

We also saw in class that we can create pointers to other datatypes, such as chars:

```
char myChar = 'q';

// This is great! ptr1 is designed to hold the address of a char
// (i.e., it is a "pointer to a char"), and that's what we're
// giving it.
char *ptr1 = &myChar;  // GOOD!

// This is NOT okay. We are creating a ptr that wants to hold the
// address if an integer, but we're disregarding its preference by
// trying to force it to take the address of a character. That's
// simply not what ptr2 is into.
int *ptr2 = &myChar;  // Oh nooooo! :(
```

(*Not mentioned in class.*) We could even have multiple pointers to the same variable! If we think of a pointer as an address book that can only hold one address -- or a cellphone that can only hold one phone number -- the idea of having multiple pointers to the same place in memory isn't that huge of a leap. The following situation is akin to two separate people (`p` and `q`) having a single-address-only address book, and they both just happen to be storing the address of the same person (`x`). Both `p` and `q` can tell us where `x` resides, and both of them can be used to access `x` indirectly.

```
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int x = 50;

   // We create two pointers to x. See memory diagram below.
   int *p = &x;
   int *q = &x;

   // We see the contents of x as well as its address.
   cout << "x: " << x << endl;
   cout << "&x: " << &x << endl << endl;

   // We see that p contains &x but has its own memory address.
   cout << "p: " << p << endl;
   cout << "&p: " << &p << endl << endl;

   // We see that q also contains &x but has its own memory address.
   cout << "q: " << q << endl;
   cout << "&q: " << &q << endl;

   return 0;
}
```

memory diagram

```
main():

  x   0x7fb4413dec24
  +----------------+
  |       50       |
  +----------------+

  p   0x7fb4413dec28  <-- p has its own unique address
  +----------------+
  | 0x7fb4413dec24 |
  +----------------+

  q   0x7fb4413dec30  <-- q has its own unique address
  +----------------+
  | 0x7fb4413dec24 |
  +----------------+
```

output

```
x: 50
&x: 0x7fb4413dec24

p: 0x7fb4413dec24
&p: 0x7fb4413dec28

q: 0x7fb4413dec24
&q: 0x7fb4413dec30
```

Treasure Hunt

Consider the following function that we saw earlier this quarter when discussing pass-by-reference functions:

main.cpp

```
#include <iostream>
#include "console.h"
using namespace std;

int treasureHunt(int& a, int& b, int& c)
{
   int totalBooty = 0;

   totalBooty += a;
   totalBooty += b;
   totalBooty += c;

   a = 0;
   b = 0;
   c = 0;

   return totalBooty;
}

int main()
{
   int treasureHoard1 = 200;
   int treasureHoard2 = 300;
   int treasureHoard3 = 500;

   cout << treasureHunt(treasureHoard1, treasureHoard2, treasureHoard3) << endl << endl;

   cout << "treasureHoard1: " << treasureHoard1 << endl;
   cout << "treasureHoard2: " << treasureHoard2 << endl;
   cout << "treasureHoard3: " << treasureHoard3 << endl;

   return 0;
}
```

output

```
1000

treasureHoard1: 0
treasureHoard2: 0
treasureHoard3: 0
```

We saw in class today that we could accomplish the same thing with pointers, like so -- and I observed that on our treasure hunt, we use 🌟💫✨*stars*🌟💫✨ to guide us through the perilous seas of memory (by which I mean the `*` operator for dereferencing) just like sailors of old:

main.cpp

```
#include <iostream>
#include "console.h"
using namespace std;

int treasureHunt(int *a, int *b, int *c)
{
   int totalBooty = 0;

   // Print memory addresses contained in a, b, and c. These are like treasure maps
   // that help us navigate the perilous seas of memory to reach our treasure hoards!
   cout << "a: " << a << endl;
   cout << "b: " << b << endl;
   cout << "c: " << c << endl;

   // If we didn't dereference a, b, and c below, we would just be attempting to add
   // memory addresses to totalBooty rather than going to main() and getting the
   // integer values that a, b, and c are pointing to.
   totalBooty += *a;
   totalBooty += *b;
   totalBooty += *c;

   // If we didn't dereference a, b, and c below, we would just be attempting to set
   // these local pointers to zero rather than going back to main() and setting the
   // various treasureHoard variables to zero.
   *a = 0;
   *b = 0;
   *c = 0;

   return totalBooty;
}

int main()
{
   int treasureHoard1 = 200;
   int treasureHoard2 = 300;
   int treasureHoard3 = 500;

   // Print memory addresses of treasure hoard variables.
   cout << "&treasureHoard1: " << &treasureHoard1 << endl;
   cout << "&treasureHoard2: " << &treasureHoard2 << endl;
   cout << "&treasureHoard3: " << &treasureHoard3 << endl;

   // Notice that we need the ampersands (&) below because our function is using
   // three pointer parameters.
   cout << treasureHunt(&treasureHoard1, &treasureHoard2, &treasureHoard3) << endl;

   cout << "treasureHoard1: " << treasureHoard1 << endl;
   cout << "treasureHoard2: " << treasureHoard2 << endl;
   cout << "treasureHoard3: " << treasureHoard3 << endl;

   return 0;
}
```

memory diagram (while in the treasureHunt() function, before wiping out the three hoards)

```
treasureHunt():

  totalBooty (0x7fd0223e0c04)
  +----------------+
  |       0        |
  +----------------+

  a                   0x7fd0223e0bf8
  +--------------------------------+
  |          0x7fd0223e0c2c        |
  +--------------------------------+

  b                   0x7fd0223e0bf0
  +--------------------------------+
  |          0x7fd0223e0c30        |
  +--------------------------------+

  c                   0x7fd0223e0be8
  +--------------------------------+
  |          0x7fd0223e0c34        |
  +--------------------------------+


main():

  treasureHoard1 (0x7fd0223e0c2c)
  +----------------+
  |      200       |
  +----------------+

  treasureHoard2 (0x7fd0223e0c30)
  +----------------+
  |      300       |
  +----------------+

  treasureHoard3 (0x7fd0223e0c34)
  +----------------+
  |      500       |
  +----------------+
```

output

```
&treasureHoard1: 0x7fd0223e0c2c
&treasureHoard2: 0x7fd0223e0c30
&treasureHoard3: 0x7fd0223e0c34
a: 0x7fd0223e0c2c
b: 0x7fd0223e0c30
c: 0x7fd0223e0c34
1000
treasureHoard1: 0
treasureHoard2: 0
treasureHoard3: 0
```

Arrays

After exploring the basics of pointers, I shifted gears a bit to talk about arrays. We saw the syntax for creating an array and accessing its elements.

An array is a variable that is able to hold multiple values of some type. An array is made up of **cells**. Each cell holds a single value. Those cells are numbered starting at 0 (zero); an array of length *n* has cells 0 through (*n* - 1).

(*Important note!*) If we do not initialize the cells in an array, they contain unpredictable garbage values.

Recall that the elements in an array are stored in a contiguous block in memory. When we apply an offset to an array (that's the index in square brackets), that tells C++ to go to the beginning of the array and skip forward a certain number of places in memory. C++ figures out how far to skip ahead in memory based on its knowledge of how much memory a single cell takes, given the type of the array in question.

(*Key take-away!*) Accessing the i^{th} element of an array is an O(1) operation.

For example:

main.cpp

```
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   // Creates an array of 5 integers. They are indexed 0 through 5.
   int array[5];

   // Print contents of array. The cells contain unpredictable garbage values by
   // default.
   for (int i = 0; i < 5; i++)
   {
      cout << array[i] << endl;
   }

   return 0;
}
```

memory diagram

```
main():

  array (0x7f762d3dec20)
  +-----+-----+-----+-----+-----+
  | ??? | ??? | ??? | ??? | ??? | <-- uninitialized (garbage values)
  +-----+-----+-----+-----+-----+
     0     1     2     3     4
```

output

```
-1345686632
22008
834537024
32626
2
```

When I first introduced arrays today, I mentioned that they're very similar to vectors. We saw that there are some key distinctions, though:

- Unlike vectors, arrays do not grow automatically to accommodate new elements. The size of an array is set in stone when we declare it.
- Unlike vectors, arrays do not have built-in functions like `size()` , `add()` , and `remove()` .
- The Stanford C++ `Vector` is a class, and it uses arrays behind the scenes. In contrast, arrays are built into the C++ language in the same way that primitive data types like `int` , `float` , `double` , and `char` are. They're one of the fundamental building blocks we use to create new classes in C++.
- When we access a cell in an array, C++ does not check whether the given index is out of bounds. In contrast, the Stanford C++ vector performs a check every time we access a vector index and throws an error if that index is out of bounds.

The Relationship Between Pointers and Arrays: Naked Array Variable Names

Toward the end of class, I showed that if we print a naked array variable name (i.e., an array variable with no square brackets attached), we get the base address of the array (i.e., the address of cell zero):

main.cpp

```
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int array[5];

   // Prints addresses of all cells in the array.
   for (int i = 0; i < 5; i++)
   {
      cout << "&(array[" << i << "]): " << &(array[i]) << endl;
   }

   // Prints base address of array. Notice this is the same as &(array[0]).
   cout << endl << "Base address of array: " << array << endl;

   return 0;
}
```

output

```
&(array[0]): 0x7f762d3dec20
&(array[1]): 0x7f762d3dec24
&(array[2]): 0x7f762d3dec28
&(array[3]): 0x7f762d3dec2c
&(array[4]): 0x7f762d3dec30

Base address of array: 0x7f762d3dec20
```

So, `array` looks a lot like a pointer. It contains, in fact, the address of an integer -- the first integer in our array. It stands to reason that if we create a pointer of type `int *`, we should be able to use that to loop through our array, as well. The square brackets operator in C++ acts as an offset whether applied to an array variable or an actual pointer:

main.cpp

```cpp
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int array[5] = {10, 15, 20, 25, 30};

   // p now contains the base address of the array.
   int *p = array;

   // Print all values in the array using p.
   for (int i = 0; i < 5; i++)
   {
      cout << p[i] << endl;
   }

   return 0;
}
```

output

```
10
15
20
25
30
```

Note that while an array might look a lot like a pointer, the key difference is that a pointer can be assigned a new value, causing it to point elsewhere. An array variable name, on the other hand, is bound to the array it represents and cannot be made to point elsewhere.

Arrays Are Dangerous! (and Segmentation Faults)

We saw in class that we can accidentally go out of bounds in an array. This is so dangerous! We can corrupt memory this way and get into all kinds of wacky trouble. I will expand upon this in the lecture notes sometime soon.

Supplementary Pointers to Nowhere: `nullptr`

If you ever have a pointer that is, for the moment, not pointing anywhere useful, you can signify that by setting it equal to `nullptr` (pronounced "null pointer"). Note that dereferencing a null pointer will give you a segmentation fault. For example:

```cpp
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int *p = nullptr;
   *p = 50;  // YIKES! Segmentation fault!

   return 0;
}
```

We will explore the usefulness of null pointers in a future lecture.

Supplementary An Obscure Dereferencing Trick

Just for fun, here is another way we can use pointers to change the value stored in a variable:

```
#include <iostream>
#include "console.h"
using namespace std;

int main()
{
   int i = 0;
   *&i = 55;

   // Print the result to verify that worked.
   cout << i << endl;

   return 0;
}
```

The star and address operators are processed from right to left in C++. So, that `*&i` line first gets the address of `i`, and then we dereference it with the star operator (i.e., we *go to that address*). That takes us to the variable `i`, of course, and we put the value 55 there.

Accordingly, we can also do something like this:

```
*&*&*&*&*&*&*&*&*&*&*&*&i = 55;
```

The following, however, does not work. Once we've taken the address of a variable, we can't take the address again:

```
**&&i = 55;  // ERROR!
```

Is there any reason to use this in the real world? NO! I'm just sharing it with you to give you an idea of the kinds of things that are possible under the formal definition of all the rules of the C++ language.

What's next?

On Monday, we'll talk about dynamic memory management. We'll see how `new` and `delete` work in C++, and we'll finally implement an ADT from scratch and fully see how it works behind the scenes.

Exam Prep

For the following exercises, check your answers by attempting to compile and run the code you come up with.

1. Both declarations below create integer pointers. What reasons did I give in the notes above for preferring the second approach over the first one? What reason do some people give for preferring the first approach?

```
int* p;
int *q;
```

2. Given the following code, what are some reasonable possibilities we could use to fill in the blank?

```
int i = 10087;
int *p = &i;
int *q = _________;
```

3. In the following chunk of code, if we want to execute the line `y = &x`, what should be the data type for `y`?

```
double x = 3.14;
_____ y;
y = &x;
```

4. Are the following lines of code valid, or is the assignment on line 2 problematic since `i` has not yet been initialized (i.e., since `i` has not yet been assigned a value when we reach that line)?

```
int i;
int *p = &i;  // is this okay?
i = 50;
```

Highlight for hint on Problem #4:

To get the solution to this problem, plunk those lines of code into a new program and see if it will compile and run.

Highlight for solution to Problem #4:

Yes, this is totally fine. :) On line 2, we are only asking for the address of i. Even though we have not yet stored a meaningful value in i by the time we reach that line, i has been declared and therefore has an address that we can store in p.

5. Write a pass-by-pointer function named `samePlace()` that takes two integer pointers and determines whether those are pointers to the same **place** in memory. If so, return `true` . Otherwise, return `false` . For example:

```
#include <iostream>
#include "console.h"
#include "SimpleTest.h"
using namespace std;

// You should be able to infer the parameter types for this function
// from the way this function is called from the provided test.
bool samePlace( ??? p, ??? q)
{
   // CODE ME
}

PROVIDED_TEST("Simple test of samePlace() function.")
{
   int a = 11;
   int b = 11;
   int c = 32;

   EXPECT_EQUAL(samePlace(&a, &b), false);
   EXPECT_EQUAL(samePlace(&b, &b), true);
}

int main()
{
   runSimpleTests(ALL_TESTS);
   return 0;
}
```

Highlight for solution to Problem #5:

```
bool samePlace(int *p, int *q)
{
   // The values p and q hold are memory addresses.
   // We simply check whether the two addresses
   // they contain are the same -- i.e., whether
   // p is equal to q.
   return p == q;
}
```

6. Write a pass-by-pointer function named `sameValue()` that takes two integer pointers and determines whether those are pointers to the same **value** in memory. If so, return `true` . Otherwise, return `false` . For example:

```
#include <iostream>
#include "console.h"
#include "SimpleTest.h"
using namespace std;

// You should be able to infer the parameter types for this function
// from the way this function is called from the provided test.
bool sameValue( ??? p, ??? q)
{
   // CODE ME
}

PROVIDED_TEST("Simple test of sameValue() function.")
{
   int a = 11;
   int b = 11;
   int c = 32;

   EXPECT_EQUAL(sameValue(&a, &b), true);
   EXPECT_EQUAL(sameValue(&b, &b), true);
   EXPECT_EQUAL(sameValue(&b, &c), false);
}

int main()
{
   runSimpleTests(ALL_TESTS);
   return 0;
}
```

Highlight for solution to Problem #6:

```
bool sameValue(int *p, int *q)
{
   // We must dereference both q and p to determine
   // whether they point to the same value. It is
   // possible for them both to point to the same value
   // even if they point to different addresses in
   // memory (as seen in the test case above where
   // sameValue(&a, &b) is expected to return true.
   return *p == *q;
}
```

7. Use pointers to write a `swap()` function that takes the addresses of two variables and then swaps their values. By passing addresses to a function, you can use them to modify variables you created back in your calling function! For example:

```
#include <iostream>
#include "console.h"
#include "SimpleTest.h"
using namespace std;

void swap(int *ptr1, int *ptr2)
{
   // CODE ME
}

PROVIDED_TEST("Simple test of swap() function.")
{
   int i = 56;
   int j = 10087;

   // Notice that we're giving the addresses of i and j to the
   // swap() function. That will enable swap() to change the
   // values of i and j from outside of this test case()!
   swap(&i, &j);

   EXPECT_EQUAL(i, 10087);
   EXPECT_EQUAL(j, 56);
}

int main()
{
   runSimpleTests(ALL_TESTS);
   return 0;
}
```

Highlight for solution to Problem #7:

```
void swap(int *ptr1, int *ptr2)
{
   int temp = *ptr1;
   *ptr1 = *ptr2;
   *ptr2 = temp;
}
```

8. Consider the following:

```
#include <iostream>
#include "console.h"
using namespace std;

void doTheThingForRealsies(int *a)
{
   *a = 12;
}

void doSomething(int *a)
{
   doTheThingForRealsies( ??? );
}

int main()
{
   int x = 55;

   doSomething(&x);

   cout << "x = " << x << endl;

   return 0;
}
```

How do we call `doTheThingForRealsies()` from `doSomething()` in order to empower that function to change the value of `x` back in `main()` ? If you create diagrams of what's happening in memory and scrutinize the data types involved (with particular focus on the data types for the arguments to the `doSomething()` and `doTheThingForRealsies()` functions), can you discover how to complete that function call?

Highlight for solution to Problem #8:

doTheThingForRealsies(a);

Highlight for an explanation of the solution given above:

Within the doSomething() function, a is a pointer to an integer; it contains the address of an integer. That's exactly what doTheThingForRealsies() wants to receive as an argument.

9. (*Synthesis*) Push the limits of your pointer knowledge and synthesize new information by reasoning through this question: In the following code, if we want `z` to hold the address of `p` , what should its data type be? (Hint: It's not `int *z` .)

```
int i = 56;
int *p = &i;
_______ z = &p;
```

10. For additional reinforcement, or to check your understanding of pointers, work through this short worksheet:

- Sean's CS106B Pointers Worksheet (PDF)
- Pointers Worksheet Solution (PDF)

11. As always, the textbook and next week's section are chock full of great exercises and additional examples to help reinforce this material.